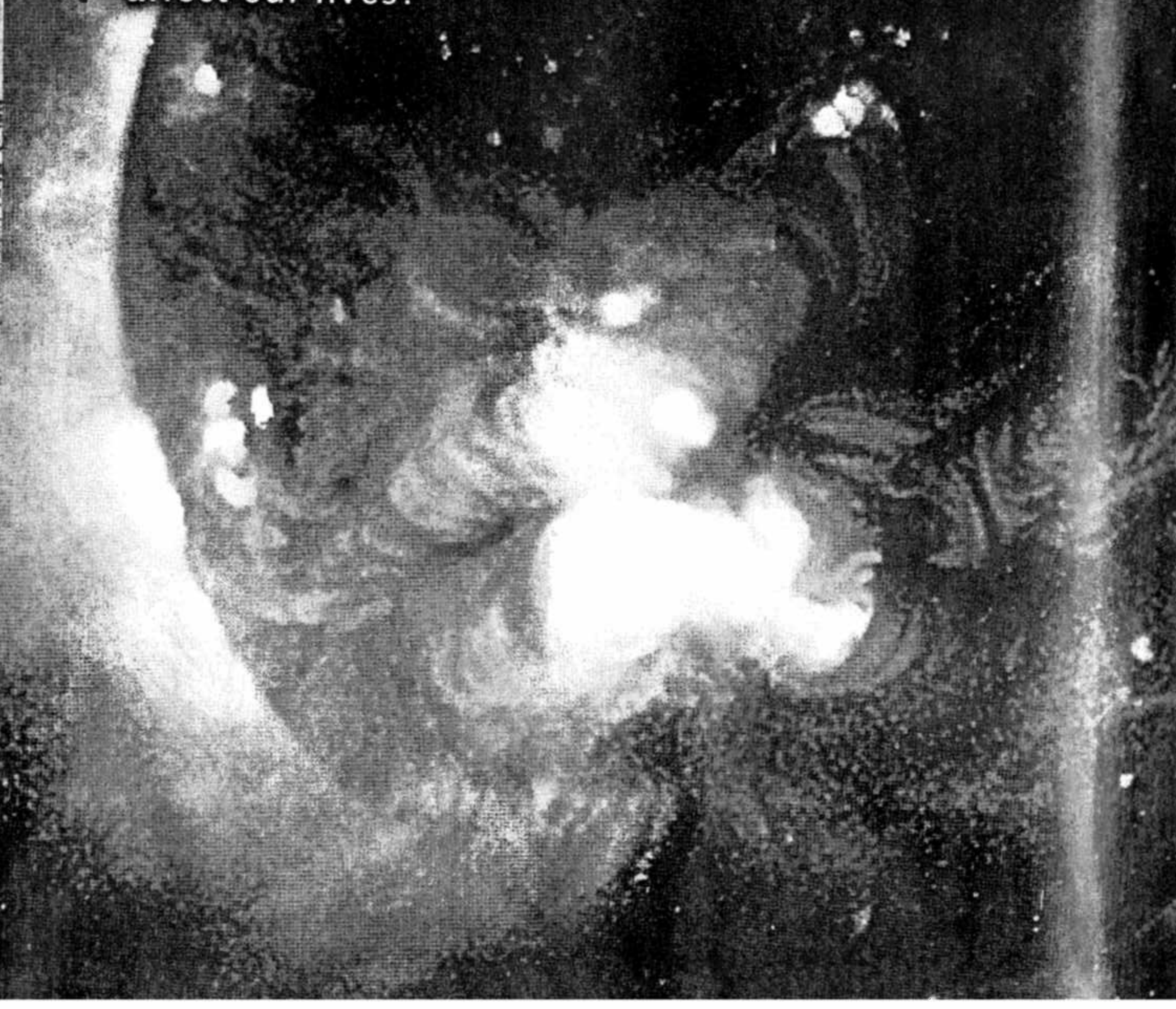
The Sun and the Solar System

CHAPTER 26

In this x-ray image, our sun resembles a sphere-shaped volcanic inferno. Although the sun is millions of kilometers away, it is Earth's primary source of energy.

How do the reactions inside the sun affect our lives?



CHAPTER 26

PREVIEW

▶ Focus Questions

In this chapter you will study the sun and learn more about the key questions listed below.

Section 1 What is the sun's structure and source of energy?

Section 2 How have observations made by scientists in the past contributed to our understanding of the sun and the universe today?

▶ Review Topics

As you investigate the sun, you will need to use information from earlier chapters.

- scientific theories and laws **(pp. 32–33)**
- Earth's revolution **(p. 80)**
- elements **(p. 90)**
- atoms and their structure **(p. 91)**

▶ Reading Strategy

Connect

As you read Chapter 26, consider your everyday experiences involving the sun. Make connections between what you observe of the sun and what you are reading.

INTERNET RESOURCES
CLASSZONE.COM

At our Web site, you will find the following Internet support for this chapter.

DATA CENTER

EARTH NEWS

VISUALIZATIONS

- Sun at Different Wavelengths

LOCAL RESOURCES

CAREERS

INVESTIGATIONS

- Why Does the Sun Appear to Change Size?
- How Does the Sunspot Cycle Affect Earth?

26.1

KEY IDEAS

The sun is vastly larger than any of the rest of the objects in the solar system.

The sun gets its energy from the fusion of light elements into heavier ones.

KEY VOCABULARY

- fusion
- plasma
- photosphere
- chromosphere
- corona
- sunspot
- solar wind
- aurora

The Sun's Size, Heat, and Structure

Compared to Earth, the sun is enormous. It has a diameter of about 1,400,000 kilometers, which is more than three times the distance from Earth to the moon, the longest distance humans have traveled in space. It would take a jet flying at three times the speed of sound more than two months to fly all the way around the sun. If multiple Earths could be placed inside the sun, more than a million would fit inside.

Although these examples give you an idea of how large the sun is compared to Earth, the sun is not a large star. If the sun's diameter were the size of a milk-bottle cap (about 3 centimeters), then the diameter of the largest star known, Epsilon Aurigae, would be the size of a football field.

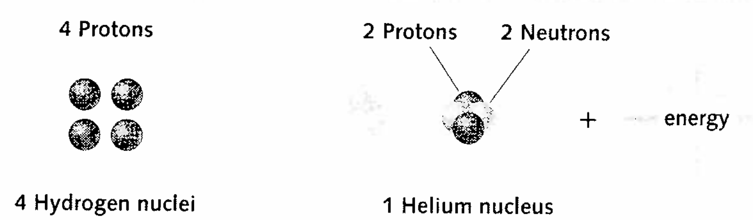
The Sun's Energy

All stars get their energy from fusion. **Fusion** is the combining of the nuclei of lighter elements to form a heavier element. You may be familiar with the famous equation $E = mc^2$ (energy is equal to mass times the speed of light squared). This equation expresses that matter can be converted into energy, which is what happens during fusion.

A star is a place of intense heat and pressure—so intense that atoms are torn apart into their component nuclei and electrons. As a result, elements such as hydrogen and helium exist as plasma.

A **plasma** is a fourth state of matter consisting of charged particles—the nuclei, or ions, which have a positive electric charge, and electrons, which have a negative charge. The nuclei normally repel each other. Due to the speed at which they move, however, and the crowding and the heat, this normal repulsive force may be overcome, and the nuclei fuse.

Fusion of Hydrogen into Helium



When four hydrogen nuclei, (or protons) come together, they produce a helium nucleus of two protons and two neutrons. Energy is released in this reaction.

When the nuclei fuse, some of their mass is converted into energy. This mass conversion is what the equation $E = mc^2$ predicts. The mass of the particles involved at the start of a fusion reaction is greater than the mass of the particles at the end; the missing mass has been converted to energy. The amount of energy produced varies depending on the kinds of elements involved in the fusion reaction.

The Sun's Layers

Although astronomers have never actually observed the interior of the sun, they have developed models of the sun's structure. The energy produced inside the sun that pushes outward is balanced by the force of gravity drawing the outer layers inward.

The sun's core consists mostly of hydrogen and helium ions in a plasma state, which is more than 100 times as dense as water. Temperatures in the core reach about 15,600,000°C.

Around the core lies the radiative zone, another layer of plasma. It is cooler than the core; its temperature ranges from about 8,000,000°C near the core to about 2,000,000°C near the convection zone. In the convection zone, rising and falling currents of plasma carry energy to the sun's surface, where it is radiated out into space as sunlight.

At the **photosphere,** the visible surface of the sun, the tops of these currents form structures called granules. A granule may be about 1,000 km wide and last about 20 minutes. The photosphere is much cooler than the convection zone, with a temperature of about 6,000°C.

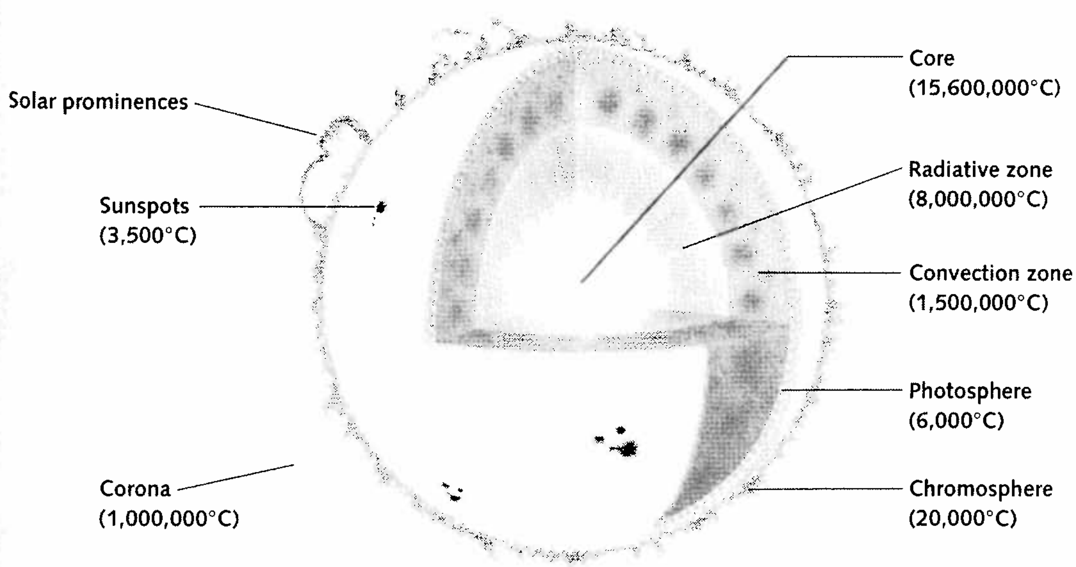
The sun has an atmosphere, although it is radically different from Earth's. The inner layer of the sun's atmosphere, the **chromosphere,** extends thousands of kilometers above the photosphere. Its 20,000°C temperature causes the hydrogen within it to emit light with a distinctive reddish color. Among the chromosphere's features are solar prominences, dense clouds of material suspended above the sun's surface by magnetic fields. They can erupt off the sun in just a few minutes or hours, extending thousands of kilometers into space before falling back to the sun's surface.

The sun's **corona** is its thin outer atmosphere, which is a million times less bright than the photosphere. Even so, the corona is surprisingly hot, with a temperature ranging from 1,000,000°C to 3,000,000°C.

VISUALIZATIONS CLASSZONE.COM

Examine the sun at different wavelengths.
Keycode: ES2601

The Sun's Layers



Features on the Sun

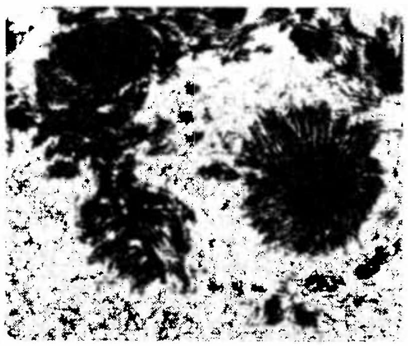
The sun is about 150 million kilometers away from Earth (a distance astronomers call an astronomical unit, or AU). Despite this distance, astronomers are able to observe changes on the sun's surface, such as the sunspot cycle, and recognize the effects the sun has on Earth.

Sunspots

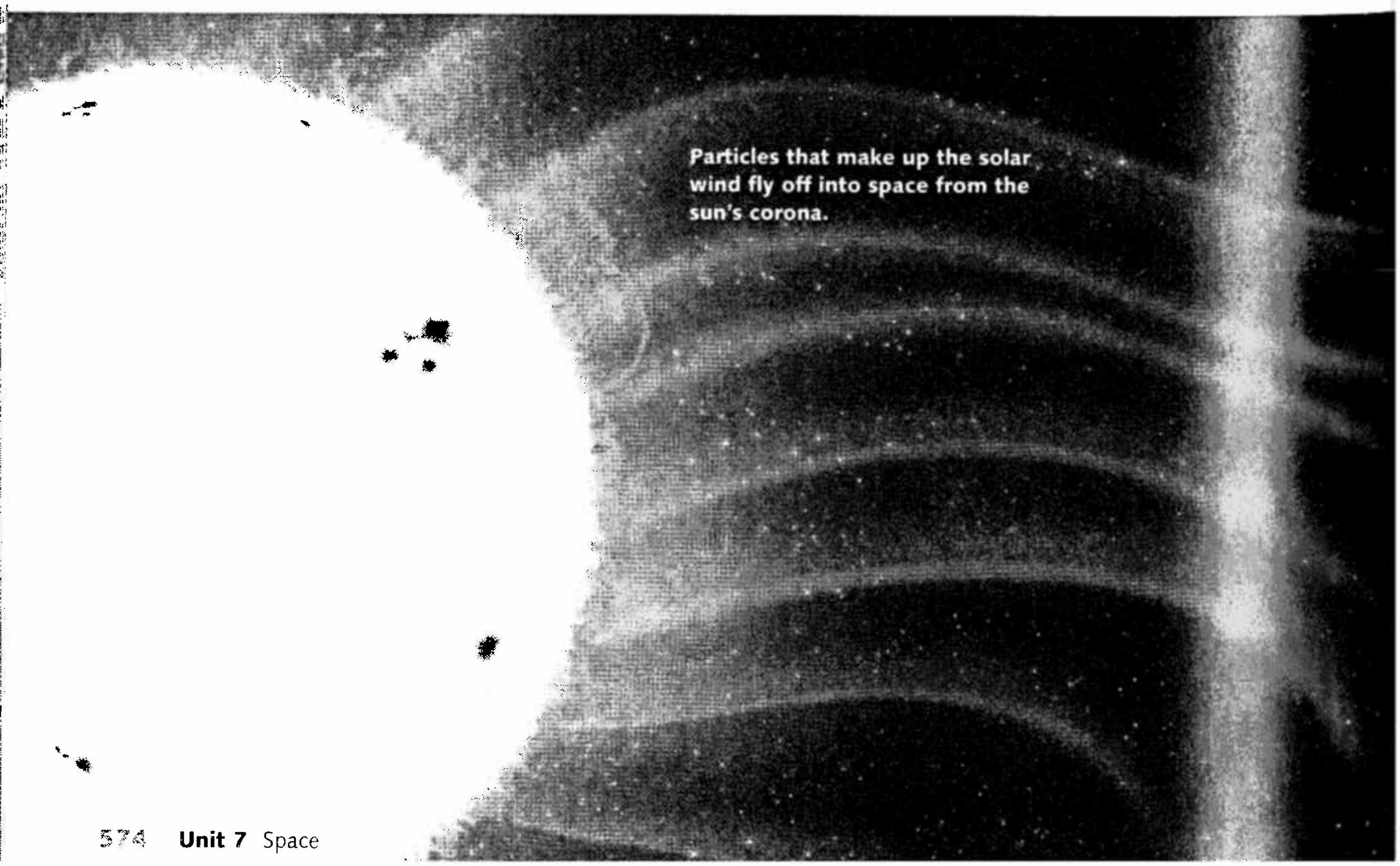
Sunspots are dark spots on the photosphere. Some sunspots are barely visible, but others are four times larger than Earth's diameter. Smaller sunspots may last only a few hours, whereas larger ones may remain visible for a few months. Sunspots are actually very hot and bright; they look dark in photographs only because the surrounding photosphere is so much hotter and brighter. The magnetic field associated with a sunspot is about 1000 times stronger than the magnetic field of the surrounding photosphere.

As seen from Earth, sunspots move from left to right across the sun's surface. This motion was the first hint that the sun rotates on its axis. Because the sun is not solid, its rate of rotation varies from place to place. The rate of rotation at the sun's equator is a little over 25 days for one rotation. Near the poles, the rate is about 34 days for one rotation.

The number of sunspots visible on the photosphere changes from day to day. At times of peak sunspot activity, more than 100 can be counted on the sun's surface. During periods of low sunspot activity, several days may pass when no spots are visible. The sunspot cycle averages about 11 years from one period of peak activity to the next.



SUNSPOTS The frequency of sunspots is predictable, following an 11-year cycle.



The Solar Wind and Magnetic Storms

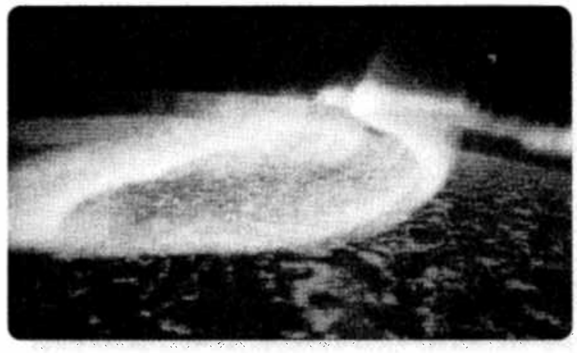
The corona gives off a constant stream of electrically charged particles called the **solar wind.** These particles—mostly protons and electrons—fly into space in all directions at a speed of about 450 kilometers per second, reaching Earth in a few days. There, they are deflected by the Earth's magnetic field, as shown below.

Some solar events produce huge gusts of solar wind. Large openings, called coronal holes, sometimes appear in the corona. Solar wind pours from coronal holes in a great torrent of particles.

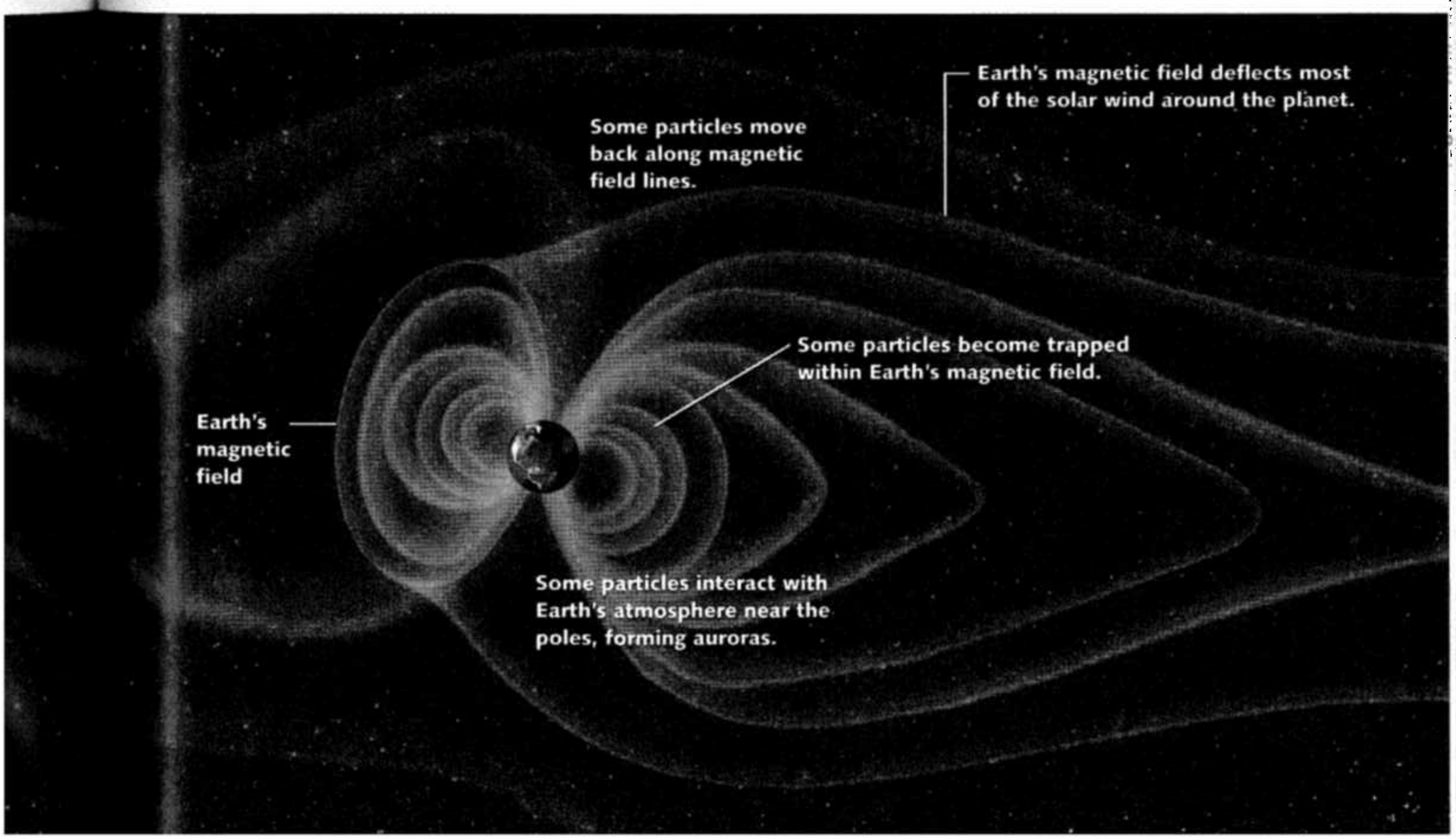
Solar flares are another source of solar wind bursts. Solar flares are outbursts of light that rise up suddenly in areas of sunspot activity. Small solar flares last only minutes; large ones may last for hours. The number of solar flares increases as the number of sunspots increases.

Earth's magnetic field shields the planet's surface from the solar wind. Without the magnetic field, Earth's surface would be bombarded by particles that are very harmful to life.

As the solar wind blows past Earth, some particles interact with Earth's magnetic field and upper atmosphere, causing **auroras,** which are displays of color and light appearing in the upper atmosphere. Auroras, also called northern and southern lights, are common events in the regions near Earth's magnetic poles.



AURORA IN SPACE Auroras like this one result from the solar wind interacting with Earth's magnetosphere and atmosphere.



CAREER

Solar Physicist

Solar physicists have the challenge of studying an object that is located almost 150 million kilometers away. Despite the sun's distance from Earth, solar physicists can use a variety of methods to study it. They study the sun's features by analyzing data from satellite instruments, making computer models, and applying the laws of physics. As a result, solar physicists are better able to understand how the sun works and to more accurately predict its effects on Earth. Many solar physicists enjoy the freedom to choose their topics of research. Some develop hypotheses based on theoretical physics. Some others study effects of the sun on our everyday life. For example, some solar physicists study how solar flares affect electronic devices such as cellular phones.

Most solar physicists find a background in math, physics, and computer science to be very useful. Solar physicists usually hold doctoral degrees in astrophysics or another related field. After receiving their degrees, most go on to postdoctoral positions at research institutions, where they gain research experience and refine their area of interest.

Many solar researchers are affiliated with the Solar and Heliospheric Observatory (SOHO), a satellite with instruments onboard that are devoted to studying different features of the sun.

SOLAR PHYSICISTS such as Theresa Kucera, a SOHO team scientist, use a variety of instruments to study the sun.

CAREERS
CLASSZONE.COM

Learn more about a career as a solar physicist.
Keycode: ES2602

Magnetic storms occur on Earth when the particles thrown out by coronal holes and solar flares are added to the constant solar wind produced by the corona. At such times, auroras are visible in middle latitudes as well as in polar areas. Electrical surges following large solar flares may disrupt cellular telephone service and damage unprotected electrical appliances.

26.1 Section Review

1. **How does a plasma differ from a gas?**
2. **Describe how the temperature of the sun changes as you move from the sun's core out to the corona.**
3. **How does the solar wind affect Earth?**
4. **CRITICAL THINKING Use your knowledge about Earth's magnetic field and solar winds to explain why auroras are not always visible from temperate regions.**
5. **BIOLOGY Mars has either no magnetic field or a very weak one. Why does this fact make it unlikely that life exists at the present time on the surface of Mars?**

Observing the Solar System: A History

When you look up and notice that the sun has moved from east to west over the course of a few hours, doesn't it seem as though Earth is standing still and the sun is moving across the sky? This perception—that Earth is stationary—was the basis of ancient Greek theories that prevailed for over two thousand years.

26.2

KEY IDEA

Throughout history scientists have developed models to account for their observations of the stars and planets. The work of past scientists contributes to today's sun-centered model of the universe.

KEY VOCABULARY

- geocentric
- heliocentric
- gravitation

The Movements of Planets and Stars

For thousands of years, the predominant model of the universe stated that Earth stood still at the center of the universe. Such a model of the universe is called a **geocentric** (JEE-oh-SEN-trihk), or Earth-centered, model.

As long as 6000 years ago, astronomers were recording the movements of the stars. They noted that the stars appeared to move across the sky, but they did not move in relation to each other. To explain the apparent motions of the stars, early astronomers envisioned the stars as holes in a solid celestial sphere that surrounded Earth. Beyond the sphere, they imagined, was a source of intense light that shone through the holes. They concluded that the stars moved around Earth as the sphere rotated.

Early astronomers also noticed that the same constellations, or groups of stars, became visible at the same time every year. People in many different cultures noticed this phenomenon and used the changing constellations as a basis for a calendar.

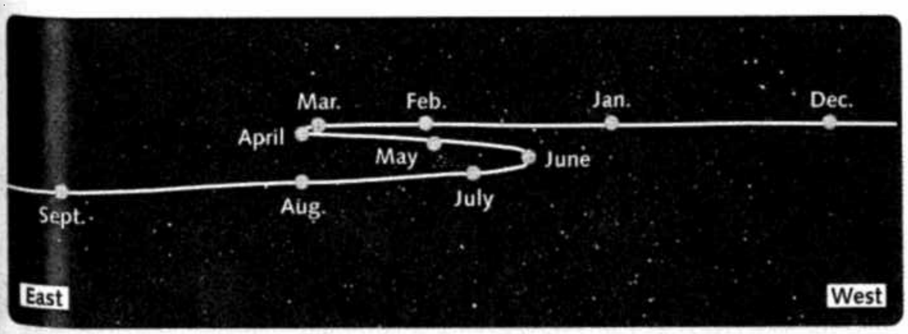
Not all points of light in the sky are fixed in constellations. A few seem to wander across the sky, changing position over the course of days, weeks, and months. These wandering points of light are planets, and early astronomers inferred correctly that planets are closer to Earth than the stars are.

Early astronomers noticed that most of the time the planets moved eastward in front of the background of constellations. Periodically, however, the planets stopped moving eastward and moved westward for a few weeks, then resumed their eastward paths. This pattern of apparent backward motion is called retrograde motion.

Scientific Thinking

DEVELOP MODELS

Design a way to demonstrate retrograde motion.



RETROGRADE MOTION Viewed from Earth, the planet Mars seems to go backward during its orbit. The effect is due to Earth catching up with and passing Mars.

25-Minute

Mini LAB

Orbital Forces

Materials

- tennis ball
- string

Procedure

1. Attach the tennis ball to one end of the string.
2. Hold the other end of the string and swing the ball in a circle.
3. Let go of the string and observe the direction in which the ball travels.
4. On paper, draw a circle, representing the ball's movement before you released it. Label the center of the circle as you. Draw an arrow from the circle to represent the ball's movement after release

Analysis

What does the ball represent in the Earth–sun system? What do you represent? What does the string represent? Explain the concepts behind your drawing, especially the arrow.

Ptolemy's Geocentric Model

The Greek astronomer Ptolemy (TAHL-uh-mee) lived in Egypt in the second century A.D. Ptolemy was puzzled by retrograde motion, so he developed a system that allowed him to predict where planets would appear in the sky at a given time. To make his predictions, he needed to account for retrograde motion.

Ptolemy succeeded in developing the first model that could be used to predict the locations of the planets. He imagined the planets on small circular orbits, called epicycles. The center of each small orbit moved aroun Earth on a larger circular orbit called a deferent. Retrograde motion occurre when the planet moved along the part of the epicycle that an observer on Earth could see. Ptolemy's model didn't work perfectly—observations didn't always correlate with what the model predicted. However, Ptolemy's model was used by astronomers until the 16th century.

Copernicus's Heliocentric Model

The Polish astronomer Nicolaus Copernicus (koh-PUR-nuh-kuhs) (1473–1543) proposed a **heliocentric** (HEE-lee-oh-SEN-trihk), or sun-centered, model of the solar system. Copernicus suggested that Earth was a planet, that it rotated, and that Earth and the other planets revolved around the sun. The heliocentric model is the basis for our modern understanding of the universe.

Astronomers observe what appears to be retrograde motion because each planet orbits the sun counterclockwise at a different distance and at a different speed. For example, Earth moves faster in its orbit than Mars does. Whenever Earth overtakes and begins to pass Mars, Mars appears to move west, or backward, among the stars. The effect is similar to what you experience when the car you are riding in down the highway passes another car; both cars are still moving forward, but the slower car appears to move backward.

After Earth has fully passed Mars, Mars's normal motion appears to resume. However, the planet never stopped revolving counterclockwise.

Tycho, Kepler, and Planetary Motion

Tycho Brahe (TEE-koh BRAH) was a 16th-century Danish nobleman and an observational astronomer. Like Copernicus and Ptolemy, he studied th heavens without the aid of a telescope. Instead, he devised his own instruments to observe the moon, planets, and other celestial objects.

Unlike other observers, Tycho and his assistants studied the movemer of the moon and planets throughout their orbits, rather than just at certai points. These more complete observations led Tycho to identify a number of unexpected occurrences, particularly in Mars's orbit. His records were the most precise made before the invention of the telescope.

Tycho died in 1601, before he was able to apply his data. Tycho's assistant Johannes Kepler, however, built on Tycho's lifetime of work. Through analyzing Tycho's data, Kepler discovered the unexpected

VOCABULARY STRATEGY

In the word *heliocentric, helio-* is from a Greek word for "sun," and *centric* means "having as a center." Likewise, *geo-* is from a Greek word for Earth, so *geocentric* means "having Earth as a center."

occurrences could be explained if the planets' orbits were elliptical, rather than round. That discovery led him to develop three laws that have become the foundation of celestial mechanics.

Kepler's first law of planetary motion states that the planets travel in elliptical orbits with the sun at one focus. Instead of having only a center, as a circle does, an ellipse has two foci (foci = plural of focus)on opposite sides of its center. Because the sun is at one focus of the ellipse, a planet's distance from the sun will change throughout its orbit.

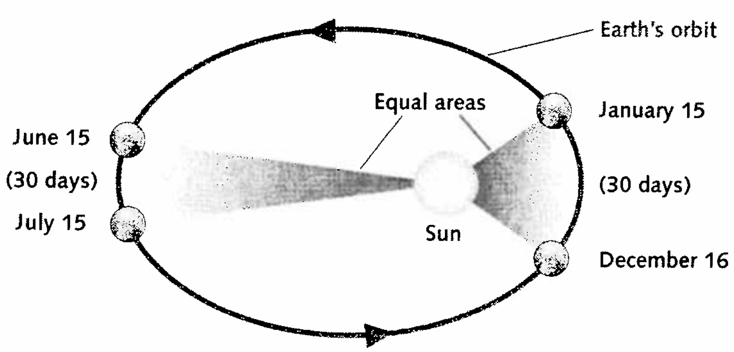
Kepler's second law of planetary motion, known as the equal area law, states that each planet moves around the sun in such a way that an imaginary line joining the planet to the sun sweeps over equal areas of space in equal periods of time. Because a planet's orbit is an ellipse with the sun at one focus, the equal area law means that the speed at which a planet travels around the sun is not constant. Kepler determined that planets travel faster when they are closer to the sun, although he was not able to explain why.

Kepler's third law of planetary motion is the harmonic law. The time it takes a planet to travel one orbit around the sun is its period. The third law of planetary motion states that the period (P) of a planet squared is equal to the cube of its mean distance (D) from the sun, or $P^2 = D^3$. The formula is used to find the mean distance between the sun and a planet if the period is known, or to find the period if the mean distance is known.

TYCHO'S OBSERVATORY Given an island by the Danish king, Tycho Brahe built Uraniborg, the best European observatory of the time.

Kepler's Equal Area Law

KEPLER'S EQUAL AREA LAW states that a line connecting Earth to the sun will pass over equal areas of space in equal times. Because Earth's orbit is elliptical, Earth moves faster when it is nearer to the sun.



According to Kepler's third law, the farther a planet is from the sun, the longer its period of revolution. One reason is that its orbit is larger. Another is that it moves more slowly than planets closer to the sun. The average speed of Earth in its orbit is about 30 kilometers a second. Mercury, nearest to the sun, moves about 49 kilometers a second.

INVESTIGATIONS
CLASSZONE.COM

Why Does the Size of the Sun Appear to Change? Watch an animation of the sun throughout the year. Make inferences about Earth's orbit around the sun.
Keycode: ES2603

Isaac Newton and the Law of Gravitation

SIR ISAAC NEWTON described gravitation, the force that keeps the planets in orbit around the sun.

Believing a force was required to keep the planets in motion around the sun, Kepler incorrectly connected that force with the sun and its rotation. Isaac Newton (1642–1727), an English scientist and mathematician, developed a very different explanation for what kept the planets in motion.

Newton's contribution to modern science is enormous. Building upon the work of his predecessors, including Kepler and Galileo, he discerned and articulated three laws of motion and the law of gravitation, which he showed mathematically to be a universal law.

Newton's first law states that an object will move forever in a straight line at the same speed unless some external force changes its direction or speed. What keeps the planets orbiting the sun, Newton said, was the force of **gravity.** The law of gravitation states that every mass exerts a force of attraction on every other mass, and the strength of that force is proportional to each of the masses and inversely proportional to the distance between them. If an object moving through space is in a path that will take it by the sun, then as the distance between the two decreases, the force due to gravity will increase. Because the sun has a far greater mass, the motion of the object, not the sun, will change noticeably in response to the force of gravity, pulling the object into orbit around the sun.

Similarly, the sun is more massive than the planets, so its force affects the planets more than the planets' gravitational forces affect the sun. The sun's gravitational pull deflects the planets from the straight-line paths they would follow under Newton's first law of motion and keeps them in elliptical orbits around the sun.

Kepler had realized in his second law of motion that the planets did not move with constant speeds. With the law of gravitation, Newton was able to explain why they do not. Newton's laws still explain most of the interactions we see between objects on Earth and elsewhere in the universe.

26.2 *Section Review*

1. **What is the main difference between geocentric and heliocentric models of the solar system?**
2. **How did Ptolemy account for retrograde motion in his model of the solar system?**
3. **Explain how Copernicus's model contributed to modern understanding of the solar system.**
4. **CRITICAL THINKING Develop a model or draw a diagram to demonstrate why Mars appears to travel westward across the sky most of the time and eastward for brief periods of time.**
5. **MATHEMATICS According to Kepler's third law, the period of a planet can be determined if the mean distance from the sun is known. Earth's distance from the sun is 1 AU (Astronomical Unit), and its period is 1 year. Jupiter's mean distance from the sun is 5.2 AU. Use Kepler's law to find Jupiter's period.**

SCIENCE & Society

Changing the Face of Science

Galileo Galilei transformed astronomy and the practice of science, and his influence lives on to this day.

How different would astronomy be if Galileo had never experimented with a telescope?

What do a swinging chandelier, a new Dutch invention for seeing across distances while at sea, and a love of mathematics have in common? All inspired the work of a man who revolutionized science: Galileo.

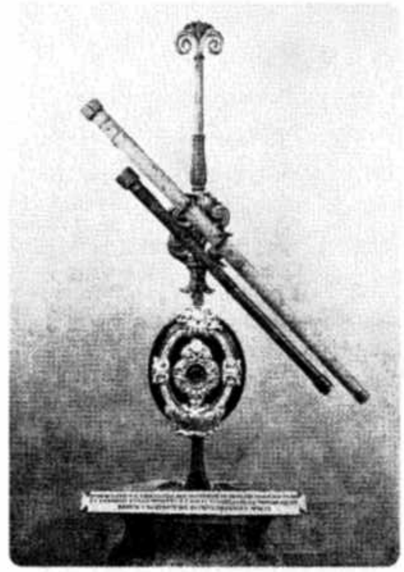
Born Galileo Galilei in Italy, in 1564, Galileo made his first important discovery as a teenager, when he observed that the swinging motion of a lamp took the same time no matter how large the swing. He measured the time by his own pulse—a sign of the belief in mathematical rationality that marked his entire career.

GALILEO is best known for his astronomy studies, but he also did groundbreaking work in other areas of science.

Experiments, mathematical quantification, and observation were all essential to Galileo's method. After hearing about a Dutch invention that made faraway objects look near, he experimented and created his own version of the device—which we know as the telescope. Galileo turned his telescope to the heavens and made revolutionary discoveries: that the sun had spots, the moon had craters and mountains, and the stars and planets looked different when viewed through the telescope, leading him to deduce that the stars are farther away from Earth than the planets.

Among the questions of physics Galileo studied was that of the behavior of falling bodies. Scientists since the Greek philosopher Aristotle had believed that heavy objects would fall faster than light ones. Galileo's studies showed this belief to be wrong. Although legend has it that to prove his point, Galileo dropped objects off the Leaning Tower of Pisa, the truth is less glamorous: he rolled objects down an inclined plane.

Galileo's work with the telescope changed astronomy forever. His work in physics showed that, contrary to the beliefs of many scientists of the time, Aristotle had not been right about everything. Galileo tested his ideas with experiments and sought the mathematical evidence behind the results.



OBSERVATIONS with his telescopes, such as this one, led Galileo to new ideas about the universe.

Through his discoveries and his practices, Galileo did much to change science from a philosophic pursuit to the evidence-driven discipline we know today. ■

Extension

SCIENCE NOTEBOOK

Think about the work you have done throughout this course. Describe a hypothesis that you made recently.

DATA CENTER
CLASSZONE.COM

Learn more about Galileo's telescopes.
Keycode: ES2604

CHAPTER 26 LAB Activity

Scale Model of the Solar System

Skills and Objectives

- ***Determine*** appropriate scales for creating a model.
- ***Construct*** a scale model of the solar system.
- ***Examine*** the model to gain insight on the solar system's structure.

Materials

- meter stick
- metric ruler
- calculator
- spherical objects of various sizes

The solar system occupies a region of space that is about 10 billion kilometers across. Light from the sun reaches Earth after eight minutes but takes over five hours to reach Pluto. The sun's volume is larger than that of all the planets combined. Jupiter's volume is larger than that of all of the other planets combined, while Pluto is smaller than Earth's moon. It is often difficult to imagine distances and size differences so great in magnitude. The dimensions of the solar system can be better understood by studying a scale model. A scale model shrinks an object proportionally so that the entire object can be viewed and studied at once. In this activity, you will have the opportunity to develop a scale model of the solar system.

Procedure

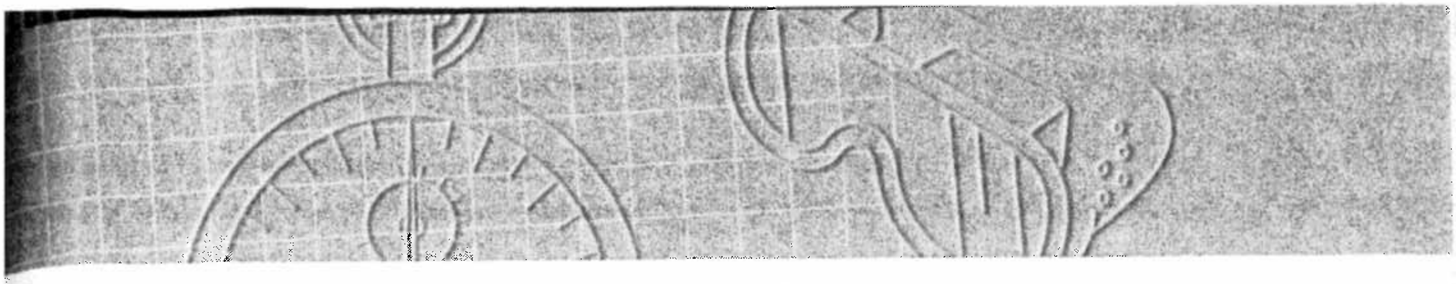
1. First choose appropriate scales for your model. Working in groups, determine how large an area your model will occupy. You may choose an area as large as you wish, but try not to allow your model to overlap other groups' models. Measure or estimate the extent of your model's area, and convert to centimeters. Divide this distance into the distance from the sun to Pluto. Round your answer to the nearest whole number. Copy the data table on the next page and record this number in the blank next to "Orbital distance scale."

2. Choose a large object to represent the sun. Describe this object in the data table at the end of the row labeled "Sun." Measure the diameter of this object in centimeters. Divide this number into the actual diameter of the sun. Round to the nearest whole number. Record your answer in the blank next to "Planetary size scale" in the data table.

3. Use the scales you have chosen in Steps 1 and 2 to fill in the columns of the table under "Diameter" and "Distance from Sun" for the model solar system. Round your answers to the nearest tenth of a centimeter for diameter and to the nearest centimeter for orbital distance. *Hint:* The diameter you calculate for the model sun should nearly equal the diameter of the object you have chosen to represent the sun.

4. Choose or make objects to represent the nine planets. The objects should be as close as possible to the diameters calculated in Step 3 for your model. Record your choices under the "Description of Object" column in the table.

5. Place the object representing the sun at the center of your model area. Use the meter stick or metric ruler to place the objects representing the planets at the appropriate distances away from the sun.



Planetary Data for Scale Model					
Planet	Actual Solar System		Model Solar System		
	Diameter (10^3 km)	Distance from Sun (10^6 km)	Diameter (cm)	Distance from Sun (cm)	Description of Object
Sun	1392.0	0			
Mercury	4.9	58			
Venus	12.1	108			
Earth	12.8	150			
Mars	6.8	228			
Jupiter	142.8	778			
Saturn	120.0	1427			
Uranus	51.8	2871			
Neptune	49.5	4498			
Pluto	2.3	5906			
Planetary size scale: 1 cm = _____ × 10^3 km			Orbital distance scale: 1 cm = _____ × 10^6 km		

Analysis and Conclusions

1. Why is it necessary to use two different scales for the size of the planets and the distance of the planets from the sun?
2. How many times larger is Earth than the object representing Earth in your model? How many times farther is Earth from the sun than the model Earth is from the model sun?
3. Did you consider anything other than size when choosing objects for your model? (For example, did you choose a blue Earth? Does your Saturn have rings?)
4. Describe two limitations of your model that prevent it from accurately representing the actual solar system.
5. Compare your model with the models of other groups. Compared to your model, which aspects of the other models more accurately depict the solar system? Which aspects of your model are more accurate?
6. The nearest star to our solar system is Proxima Centauri, which is about 38 trillion kilometers away from the sun. If you included Proxima Centauri in your model, what distance would it be from the sun?

CHAPTER 26 REVIEW

Summary of Key Ideas

26.1 The sun is enormous compared to Earth. Its surface temperature is about 6000°C; its interior is even hotter. The photosphere, chromosphere, and corona are layers of the sun's atmosphere. Granules, solar prominences, sunspots, and solar flares appear on the sun's surface. The solar wind is a stream of charged particles from the sun's corona. Some solar events cause changes in the solar wind that can affect Earth. The sun's energy is the result of the conversion of hydrogen to helium in nuclear fusion. The mass that does not convert to helium is not lost but becomes energy.

26.2 Ptolemy proposed a geocentric (earth-centered) solar system to explain planetary motion. Nicolaus Copernicus proposed a heliocentric system, in which the planets orbit the sun. Johannes Kepler used Tycho Brahe's data to develop three laws that explained the motions of the planets. Isaac Newton developed the universal law of gravitation, which helped explain the motions of planets in the solar system.

KEY VOCABULARY

- **aurora** (p. 575)
- **chromosphere** (p. 573)
- **corona** (p. 573)
- **fusion** (p. 572)
- **geocentric** (p. 577)
- **gravitation** (p. 580)
- **heliocentric** (p. 578)
- **photosphere** (p. 573)
- **plasma** (p. 572)
- **solar wind** (p. 575)
- **sunspot** (p. 574)

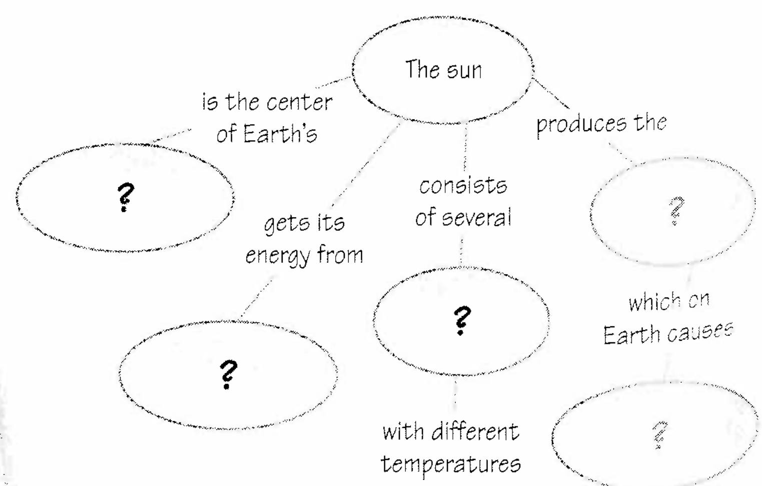
Vocabulary Review

Write the term from the key vocabulary list that best completes the sentence.

1. The __?__ is a stream of charged particles from the sun.
2. In a(n) __?__ solar system, the planets travel around the sun.
3. A type of nuclear reaction called __?__ provides the sun's energy.
4. The force of __?__ between two objects depends on their mass and their distance apart.
5. The __?__ is the outermost layer of the sun's atmosphere.

Concept Review

6. How does a plasma differ from a gas?
7. What evidence do scientists have for the sun's rotation?
8. Why does Mars appear to move backwards at certain times during its orbit?
9. What surface feature indicates that the sun's inner layers are in motion?
10. Describe Kepler's equal-area law.
11. According to Kepler's third law of planetary motion, which planet would take longer to orbit the sun, Mercury or Venus?
12. **Graphic Organizer** Copy and complete the concept map below.



Critical Thinking

13. **Apply** The average speed of the coronal solar wind is 450 km/s. How long does it take a particle in such a wind to reach Earth? (Assume that the distance from Earth to the sun is 150,000,000 km.)
14. **Infer** The Russian space station *Mir* entered Earth's atmosphere and burned up in 2001. As it spiraled toward Earth, its orbital speed increased. Why?
15. **Communicate** Explain why it is difficult to achieve nuclear fusion except near the center of stars.
16. **Infer** What would be some possible consequences for life on Earth if Earth had a weaker magnetic field?
17. **Hypothesize** Write a statement explaining why sunspots might vary on an 11-year cycle.

Internet Extension

INVESTIGATIONS CLASSZONE.COM

How Does the Sunspot Cycle Affect Earth?
Compare yearly sunspot activity with other data to find out how sunspots affect Earth.

Keycode: ES2605

Writing About the Earth System

SCIENCE NOTEBOOK The Earth system derives the major part of its incoming energy from the sun. Choose one event that takes place in Earth's atmosphere, hydrosphere, or biosphere and explain how the sun affects the transfer of materials in this event.

Interpreting Diagrams

When Venus is observed from Earth, it is never more than 45 degrees of arc from the sun. Figure A shows the positions of Earth, the sun, and Venus in a geocentric system. Three *phases,* or lighted portions of Venus visible from Earth, are also shown. In the geocentric system, Venus and the sun are always on the same side of Earth. Figure B shows the positions of Venus, Earth, and the sun in a heliocentric system and shows eight phases of Venus. Study Figures A and B and answer Questions 18–21.

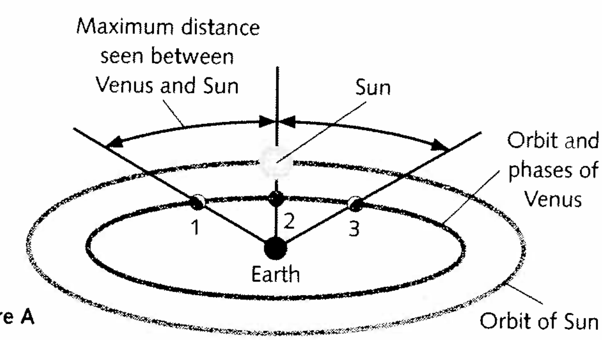


Figure A

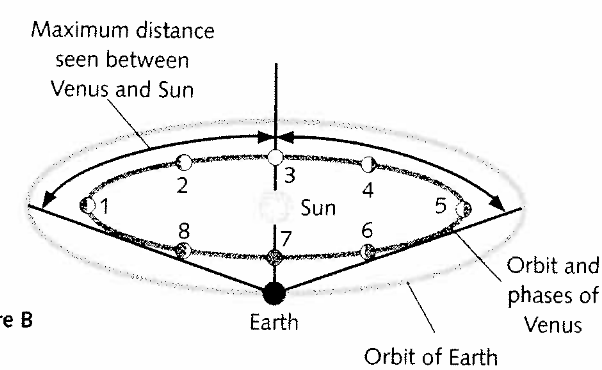


Figure B

18. Which phases in Figure B match phases 1, 2, and 3 shown in Figure A?
19. When Galileo looked at Venus with his telescope, he saw Venus in phases that are impossible in the geocentric system shown in Figure A. What phases did Galileo see?
20. Why did Galileo's observations of Venus help to disprove the geocentric model of the solar system?
21. Are there other planets that would show phases, as Venus does? Explain.